

A black and white photograph of a lake. In the foreground, there are tall, thin reeds or grasses growing out of the water. The water surface is covered with many small, dark, rectangular objects, possibly floating debris or small boats. In the background, there is a distant shoreline with some trees and a few small buildings. The sky is dark and overcast.

SEDIMENT RESPIRATION AND
MINERALIZATION IN TEMPERATE LAKES

WILHELM GRANÉLI
DISSERTATION
LUND 1977

SEDIMENT RESPIRATION AND MINERALIZATION IN TEMPERATE
LAKES

WILHELM GRANÉLI

Institute of Limnology
University of Lund, Sweden

Dissertation

LUND 1977

RECENT REVISIONS AND MODIFICATIONS IN THE

PAGE

LIBRARY

Institute of Zoology
University of Lund, Sweden

Dissection



SEDIMENT RESPIRATION AND MINERALIZATION IN TEMPERATE
LAKES

Wilhelm Granéli

The dissertation is a summary of the following papers:

- I. Granéli, W. 1972. Über die Messung der Respiration an einigen limnischen heterotrophen Versuchssystemen. - Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich 117:293-304.
- II. Granéli, W. In press a. Measurement of sediment oxygen uptake in the laboratory using undisturbed sediment cores. - Vatten.
- III. Granéli, W. 1977 a. The respiratory quotient and anaerobic CO₂-production of undisturbed sediment cores. - Mimeographed. Institute of Limnology, Lund.
- IV. Granéli, W. In press b. Sediment oxygen uptake in South Swedish lakes. - Oikos.
- V. Granéli, W. 1977 b. The influence of Chironomus plumosus larvae on the oxygen uptake of sediment. - Mimeographed. Institute of Limnology, Lund.
- VI. Granéli, W. 1977 c. The influence of Chironomus plumosus larvae on the exchange of dissolved substances between sediment and water. - Mimeographed. Institute of Limnology, Lund.

The papers will be referred to by the Roman numerals above.

INTRODUCTION

Material entering a lake ecosystem and participating in the biogeochemical cycles is not completely recycled. Particulate material collects on the bottom, building up sediment. This is the natural "aging" process leading to filling and ultimate "death" of the lake. Allochthonous and autochthonous organic material constitutes an important fraction of the profundal sediment in most temperate lakes. Although there is a "historical layer" ("fossile Schicht" according to Naumann (1930)) below the surface where material does not participate in biogeochemical cycling processes, surface sediment ("aktuelle Schicht" according to Naumann) is biologically active. The surface layer of profundal sediments is the habitat of a specialized bottom fauna composed of e.g. burrowing tubificids and chironomids. Because of the accumulation of organic material, profundal sediments are also a favourable substrate for bacterial populations. However, as a consequence of intense bacterial activity in combination with low oxygen availability, anaerobic processes predominate below a thin layer of oxidized sediment. Chemical reactions, influenced by redox conditions in the sediment and involving e.g. iron, phosphorus and nitrogen, are important for the exchange of dissolved substances between sediment and water.

Sediment metabolism is complicated, and in situ rates are difficult to measure. Vertical transport and mixing probably limit the rate of many metabolic processes. Sampling of sediment and handling of sediment samples during laboratory experiments must be carefully planned to achieve reliable measurements of sediment processes.

Much work has been devoted to development of methods for measuring the total rate of sediment metabolism. Still, there are no such methods, and sediment oxygen uptake has often been used instead. To study the organic carbon cycle in a lake, measurements of sediment metabolism based on carbon dioxide are to be preferred; otherwise oxygen uptake must be

transformed to carbon dioxide production using a proper respiratory quotient ($RQ = \Delta CO_2 / \Delta O_2$).

Besides the overall rate of sediment metabolism, regulatory mechanisms are of prime interest. Sediment metabolism is regulated by temperature, oxygen availability, transport and mixing in the sediment, sedimentation rate, composition of the sediment and biomass and nature of the organism community. Our knowledge about sediment mechanisms will be greatly enhanced when microbiological investigations, analysis of the composition and rate of transformation of organic compounds in the sediment and measurement of overall sediment metabolism are coordinated. It is still not known what ultimately controls the rate of mineralization in freshwater sediments.

Studies were made by the present author to develop methods for measuring carbon dioxide production and oxygen uptake of undisturbed sediment cores (I, II). In order to convert oxygen uptake to carbon dioxide production, comparison of the two methods under controlled conditions was necessary (III). The carbon dioxide method is, in contrast to the oxygen method, useful under anaerobic conditions (I, III). Sediment oxygen uptake was measured in lakes of different trophic state and different depths during a period of one year. The influences of temperature, season and oxygen concentration on uptake rates were the main topics studied (IV). It was assumed that the availability of fresh organic material was one of the prime factors influencing sediment respiration. This aspect was studied in cores incubated at out-of-season temperatures and in cores from two lake enclosures with different amounts of algae (IV). The relationship between mixed-layer depth, annual primary production and annual sediment oxygen uptake was examined (IV, compare Hargrave 1973). Observations of oxygen uptake on undisturbed sediment cores suggested that large chironomid larvae play an important role. Laboratory experiments were performed with the addition of Chironomus plumosus larvae to sediments to study the effect on oxygen uptake (V) and release of dissolved substances from the sediment (VI).

STUDY AREA

Except Lake Årungen in southern Norway, the lakes studied are situated in the southern part of Sweden. The principle study objects were Lake Trummen and Lake Södra Bergundasjön near the city of Växjö, province of Småland, and Lake Vombsjön, province of Scania. These eutrophic lakes were chosen because water and sediment chemistry and pelagic primary production had been studied by several researchers at the Institute of Limnology, Lund. Lake Hinnasjön, Lake Växjösjön and Lake Fiolen have also been investigated previously with respect to water and sediment chemistry and primary production. The lakes are relatively shallow (max. depth 3-15 m) and usually lack a well-defined hypolimnion. Lake Ivösjön, Lake Vidöstern and Lake Stora Neden were chosen to represent lakes with a stable summer stratification.

For results of general validity, it was desirable to investigate lakes of different trophic state and with different types of sediment. The lakes studied range from naturally oligotrophic (Lake Fiolen, Lake Hinnasjön) and acidified (Lake Stora Neden) to calcareous, naturally eutrophic (Lake Vombsjön) and strongly polluted (Lake Södra Bergundasjön). Various types of sediment are found in these lakes, e.g. gyttja with high iron and humic substance content (Lake Fiolen, Lake Hinnasjön, Lake Trummen, Lake Stora Neden), calcium-rich gyttja (Lake Vombsjön) and strongly reduced sediment (Lake Årungen, Lake Södra Bergundasjön).

Although Lake Trummen is eutrophic, its sediment is more characteristic of the oligotrophic lakes in the area. The reason is that Lake Trummen was restored (1970-1971) by removal of the superficial reduced sediment from the recipient period. The sediment now exposed was deposited when Lake Trummen was still oligotrophic.

METHODS

Sediment respiration was usually measured in undisturbed sediment cores taken with a Kajak-type corer. Undisturbed cores are defined here as sediment cores with the natural stratification visually intact. Sediment and overlying water were not mixed during sampling. Sediment cores were brought to the laboratory and incubated in darkness in controlled-temperature water baths.

A new method was developed to measure the carbon dioxide produced by the sediment (I, III). By continuous flushing with carbon dioxide-free gas the carbon dioxide formed in the sediment was removed and trapped in 1 M NaOH or KOH. After 1-3 days the trapped carbon dioxide was titrated with 0.1 M HCl under nitrogen bubbling. The method has the advantage that, in contrast to closed systems, conditions in the overlying water are kept constant. Disadvantages are that the flow of gas must be constant in order to reach steady-state conditions and that the measurements are time-consuming (1-3 days for trapping sufficient carbon dioxide, 15 min. for titration). For measurement of aerobic respiration, air without carbon dioxide was used as carrier gas. Carbon dioxide-free nitrogen gas was used when anaerobic respiration was measured.

Sediment oxygen uptake was measured in closed systems (II). A PVC stopper with O-rings was pushed down into the plexiglass tube containing the sediment core, and all air was excluded. 30 ml samples for oxygen analysis were withdrawn 5-10 times, with the oxygen saturation in the overlying water decreasing about 10 percent units between each two samples. During the incubation the overlying water was gently stirred with a rotating magnetic bar. Stirring increased oxygen uptake by approximately 55 % (II).

A problem with measurements of both oxygen uptake and carbon dioxide production was the variability among replicate cores. The standard error was 5-10 % of the mean rate of respiration in replicate cores ($n = 8-15$) (II, III).

Chemical oxygen uptake of the sediment was measured in cores where the overlying water had been poisoned with mercuric chloride or formalin. These two poisons gave similar results with regard to oxygen uptake (II). Comparison with a core treated with strong gamma radiation indicated that poisons added to the water also stop all biological oxygen uptake in the sediment (II). It was shown that diffusion of oxygen through the walls of the plexi-glass tubes did not significantly affect measurement of oxygen uptake at high oxygen saturations (II).

RESPIRATORY QUOTIENTS OF SEDIMENTS

Carbon dioxide production and oxygen uptake were measured in the same cores in order to calculate the respiratory quotient, RQ (III). The mean value of RQ for four lakes of different trophic state was 0.90. This value is in close agreement with the RQ expected for organisms during aerobic metabolism (0.85). Respiratory quotients were slightly higher in sediment from the two most eutrophic lakes, Lake Södra Bergundasjön and Lake Vombsjön (0.95 and 0.96, respectively), than in sediment from the oligotrophic Lake Fiolen (0.86) and Lake Trummen (0.83). Lake Trummen is eutrophic but has an "oligotrophic" sediment. Anaerobic carbon dioxide production as a percentage of aerobic respiration was higher in Lake Fiolen (42 % of the aerobic carbon dioxide production at 20 °C) and Lake Trummen (32 %) than in Lake Södra Bergundasjön (22 %) and Lake Vombsjön (21 %) (III). Lake Södra Bergundasjön and Lake Vombsjön have highly reduced sediments.

FACTORS REGULATING THE RESPIRATION OF SEDIMENTS

Temperature

Q_{10} (the quotient between the rates of a process at $t+10$ °C and t °C) for sediment oxygen uptake was calculated for four lakes from oxygen uptake of sediment cores incubated monthly at the in situ temperature (IV). High Q_{10} values were found at low temperatures ($Q_{10} = 2.0-3.0$ at 5-10 °C),

while low Q_{10} values were noted at high temperatures ($Q_{10} = 1.3-1.6$ at $15-20^{\circ}\text{C}$). In lakes with minor variations in oxygen saturation, temperature is the main factor controlling seasonal variations in sediment oxygen uptake (IV). Similar Q_{10} values were obtained for both carbon dioxide production and oxygen uptake (I, III).

Oxygen availability

Sediment oxygen uptake was correlated with oxygen saturation in the overlying water (II). In Lake Väcksjön and Lake Vombsjön sediment oxygen uptake was low during the summer because of low oxygen levels in the bottom water (IV).

Organic material

Addition of fresh organic material (e.g. phytoplankton) to the sediment surface did not stimulate sediment oxygen uptake (IV). Two plastic enclosures in Lake Trummen contained different densities of fish feeding on the zooplankton. The fish indirectly controlled the biomass and production of phytoplankton. In spite of large differences for the two enclosures in chlorophyll and amount of sedimented algae, no significant difference in sediment oxygen uptake was detected (IV). Cores from Lake Södra Bergundasjön taken in the winter and incubated at 20°C had an oxygen uptake similar to that measured at the same temperature during summer. Also, cores made from sieved and restratified surface (0-20 cm) sediment from Lake Södra Bergundasjön had an oxygen uptake similar to the oxygen uptake of cores taken in the summer (IV). Thus the high sedimentation of organic material in Lake Södra Bergundasjön during the summer did not stimulate sediment oxygen uptake.

Annual sediment oxygen uptake for six lakes was compared to the quotient between annual primary production and mixed-layer depth. These two parameters were highly correlated after logarithmic transformation, but the slope of the regression line was less than that reported by Hargrave (1973) (IV). After a comparison of primary production, sediment oxygen uptake and sediment growth rate, it was

concluded that sediment mineralization is not proportional to sedimentation of organic material. Sediment growth rate is therefore higher in eutrophic than in oligotrophic lakes (IV).

Sediment properties

In Lake Stora Neden (max. depth 50 m) and Lake Ivösjön (max. depth 50 m) dry weight and loss on ignition of surface sediment were related to water depth. While sediment dry weight decreased with water depth, loss on ignition increased. In spite of these differences no significant variation in sediment oxygen uptake with water depth was detected (II). Sediment oxygen uptake was not related to sediment dry weight or loss on ignition. It would appear that only a part of the organic material in the sediment is labile while the bulk of the material is refractory and not important for sediment metabolism.

Macrobenthos

Tubificids added to a sediment lacking macroinvertebrates increased the rate of carbon dioxide production more than that attributed to the respiration of the larvae (I). Experiments with sieved and restratified sediment and undisturbed sediment cores to which 4th instar Chironomus plumosus larvae were added showed an increase in sediment oxygen uptake 3-4 times greater than that due to respiration of the larvae alone (V). The effect lasted for at least one month and was found both at low (5 °C) and high (20 °C) temperature.

Chironomus plumosus larvae not only increased sediment oxygen uptake but also enhanced the release of silica, phosphorus, iron and manganese from eutrophic lake sediments (VI). The increased rate of sediment respiration and release of dissolved substances caused by the addition of chironomid larvae are probably a result of an increase in the vertical mixing of the sediment and increased exchange between the interstitial water and the overlying water. Thus the rate of mineralization in lake sediment is

largely restrained by lack of mixing, allowing anaerobic conditions below the sediment-water interface and the accumulation of metabolites in the sediment.

REFERENCES

- Hargrave, B. T. 1973. Coupling carbon flow through some pelagic and benthic communities. - J. Fish. Res. Board. Can. 30:1317-1326.
- Naumann, E. 1930. Einführung in die Bodenkunde der Seen. - Die Binnengewässer 9:1-126.

ACKNOWLEDGEMENTS

For providing research facilities and for much valuable discussion and criticism I am greatly indebted to my advisor Professor Sven Björk. I also thank Anders Södergren for innumerable constructive comments and criticism of the manuscripts. Without the help of Gunnar Gahnström in the latter stages of the work it would have been difficult to finish the dissertation. Birgitta Hultberg, Karin Nilsson and Göran Bohman made many of the water and sediment analyses. Lars Bengtsson gave valuable help with the work in Lake Södra Bergundasjön. I am greatly indebted to my colleagues at the Institute of Limnology, Lund, who made available many unpublished results from the lakes studied. I finally thank Monica Magnusson, Herzilie Backhof, Gun-Britt Olsson, Michael Coveney, Folke Holm and Stanislaw Lazarek for help with drawings, typewriting, language checking and printing.

The research was supported by grants from the Royal Physiological Society at Lund and the Swedish Environment Protection Board.

Cover photos by Wilhelm Ripl (front, forest lake in Småland) and Hans Berggren (back, Chironomus plumosus larvae).



INSTITUTE of LIMNOLOGY • UNIVERSITY of LUND, SWEDEN